LUNAR PROSPECTOR
Student Resource Archive

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(AKA the Rediscovering the Moon Press Kit)

National Aeronautics and Space Administration

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GENERAL OVERVIEW

After 25 years, NASA is returning to the Moon with a mission dedicated exclusively to lunar science. Lunar Prospector, a cooperative project between NASA Ames Research Center in Moffett Field, CA and Lockheed Martin Missiles and Space in Sunnyvale, CA, is the third in NASA's new Discovery Program. Dr. Alan Binder, of the Lunar Research Institute in Gilroy, Calif., is the mission's Principal Investigator, and holds key responsibility for the scientific return of the mission. Discovery missions like Lunar Prospector put science as the highest priority. Researchers expect that the scientific data return from the Prospector mission will make major contributions toward understanding the origin, evolution and current state of not only the Moon itself, but also of Earth and the entire Solar System.

Why study the Moon?

Spacecraft have been studying the Moon for nearly four decades. The history of direct lunar exploration formally began in 1959, when probes from the Soviet's Luna spacecraft first flew by and then impacted the Moon's surface. Around the same time, NASA's Pioneer 4 passed within 37,000 miles of the Moon.

Subsequent U.S. missions, such as Ranger, Surveyor and Lunar Orbiter, photographed the lunar surface in preparation for landing astronauts. On July 20, 1969, the dream of putting a human on the Moon became reality when Neil Armstrong stepped off the Apollo 11 spacecraft and onto the rocky, dusty lunar terrain. Ensuing Apollo missions returned the first scientific samples from an extraterrestrial body to Earth — nearly 850 pounds (400 kilograms) of Moon rock.

While both Soviet and U.S. lunar missions have returned to Earth a wealth of data, including breathtaking pictures and surface rock samples, many scientific questions remain unanswered. Much of the composition and structure of the Moon is still a mystery to scientists — less than a quarter of its surface has been mapped in detail, and little is known about how it formed, what it is made of, and how it has evolved over time.

Following the successful Apollo missions, NASA formed the Lunar Exploration Science Working Group (LExSWG), comprising a dozen or so scientists. The group's goal was to prioritize what scientific questions about the Moon remained unanswered. LExSWG has reconvened periodically since then, and in 1992 drafted a final document entitled "A Planetary Science Strategy for the Moon," which outlines the science objectives and measurement requirements necessary to fully explore the Moon scientifically. These objectives are:

- How did the Earth-Moon system form?
- How did the Moon evolve?
- What is the impact history of the Moon's crust?

- What constitutes the lunar atmosphere?
- What can the Moon tell us about the history of the Sun and other planets in the Solar System?

Lunar Prospector: An exclusively lunar mission

The recent Galileo mission lunar fly-by and high-altitude spectral imaging and topographic surveys by the joint Dept. of Defense (DOD)-NASA Clementine mission have begun to crack some of the Moon's enduring mysteries, providing rough estimates of crustal composition and topography. Lunar Prospector will pick up where Apollo, Galileo and Clementine left off, providing yet another complementary piece of the ongoing research puzzle of the Moon.

An important difference from the Galileo and Clementine missions, however, is that Lunar Prospector is a targeted lunar-only mission with focused scientific goals. Although Prospector is a small spacecraft with a payload of five instruments, observations made by the spacecraft will be made over a much longer duration than previous missions to the Moon. Its polar-orbiting altitude, 63 miles (100 km) above the surface of the Moon, will be the closest any spacecraft has come to the lunar surface for a sustained period of time (orbiting for at least one year), enabling Prospector to map the entire surface. In addition, Prospector will fly over the polar regions — previous missions explored only a small portion of the Moon (around the midsection, or equator), leaving three-quarters of the lunar surface unmapped.

From the standpoint of future space exploration, the Moon may well be the site of the first extraterrestrial human outpost in the Solar System — a feat which would permit ongoing lunar and astronomy studies and long-range observation of the Earth, as well as providing a platform from which to explore the rest of the Solar System. Whether or not the Moon contains usable quantities of water and certain gases such as nitrogen, carbon monoxide and carbon dioxide is important information in determining the most feasible and cost-effective approach to lunar habitation.
Expected answers: Lunar evolution and resources

The Lunar Prospector mission's primary goal is data gathering. While Prospector will address many of the issues raised by LExSWG, complete answers will require future lunar exploration and decades of further research. The main scientific priorities for the Prospector mission are:

- to "prospect" the lunar crust and atmosphere for potential resources, including minerals, water ice and certain gases,
- to map the Moon's gravitational and magnetic fields, and
- to learn more about the size and content of the Moon's core.

MOON HISTORY

The Moon is the Earth's only natural satellite, circling in a slightly elliptical orbit at 2,300 miles per hour (3,683 km/hr). At this speed, it takes about 27 days to completely encircle the Earth, which is 240,250 miles (384,400 km) away. Because of its size and composition, planetary scientists call the Moon a "terrestrial body" — akin to Mercury, Venus, Earth and Mars.

Missions to the Moon: Past and Present

In the mid-1960s, U.S. missions called Ranger, Surveyor and Lunar Orbiter photographed the Moon's surface to determine whether the lunar terrain was hospitable enough for a future human landing. These missions succeeded in providing early pictures of the Moon's crater-filled surface. NASA's Apollo series of missions followed soon after and were the first to land humans on the Moon.

More recently, in 1994, the spacecraft called Clementine made worldwide headlines when it discovered possible indirect evidence of water ice on the Moon in a permanently shadowed miles-deep crater at the south pole. With Lunar Prospector, researchers hope to begin to solve some of the Moon's enduring scientific mysteries, including the question of whether or not water ice exists — a crucial ingredient for future lunar colonization.

Previous lunar missions brought nearly 850 pounds (400 kg) of Moon rock back to Earth. Subsequent analysis of those rock samples revealed that the Moon consists predominantly of volcanic materials, and that its composition is very similar to the Earth's. Apollo's seismic studies and density measurements also suggested that the Moon has only a tiny metallic core, roughly 15 times smaller than that of the Earth.

Lunar surface samples, however, contain important clues not only to the origin and evolution of the Moon itself, but to the beginnings of the entire Solar System. Data obtained from these Moon rocks, for instance, has narrowed the possible scenarios for the origin of the Moon to four. Scientists have concluded that the Moon formed four and a half billion years ago, when the Earth collided with a very large object (the size of Mars), ejecting raw materials that eventually became the Moon. This is known as the impact theory. Currently, the impact theory is the one most widely accepted by planetary scientists, but other theories are still plausible. Coaccretion theory holds that the Moon formed in Earth's orbit along with all the other planets in the Solar System. Fission theory states that, when the Solar System was very young, the Earth was spinning so fast [nearly 10,000 miles per hour (16,000 km/hr), or ten times its current speed], that it threw off a large chunk of material in order to stabilize itself; that chunk, the theory holds, became the Moon. Capture theory holds that the Moon was formed elsewhere in the Solar System and was seized by the Earth. Of all these theories, the impact theory fits best with all the data that has been accumulated about the Moon.

Future Lunar exploration, especially that which will determine global bulk composition of the Moon, should help scientists settle this issue.

The surface of the 38 mile (60 km)-thick lunar crust is covered with a layer of rock, called regolith, which was ground-up by the constant rain of meteoroids. The Moon’s terrain is a combination of heavily cratered highlands and smooth maria. The older and more rugged highlands formed early in lunar history (more than four billion years ago), when the lighter molten components floated to the surface of the Moon — at that time a liquid “magma ocean.” As this highland crust formed, it was sculpted by an intense bombardment of asteroid and cometary debris left over after the formation of the solar system. The younger, smoother maria — dark, volcanic plains — were formed three to four billion years ago, filling some of the enormous basins formed by the huge asteroid that struck the Moon early in its history.

Unlike the Earth, the Moon does not have a significant magnetic field, and it has no significant atmosphere. Its unprotected regolith is constantly being bombarded by the solar wind. This “wind” from the Sun continuously embeds chemical elements, such as hydrogen ions, into the lunar surface. By studying the surface of the Moon, scientists can learn a lot about the Sun.

Many other questions remain. For instance, scientists still don’t underu‰and why the crust is thicker on one side, or the nature of the Moon’s volcanic history. Lunar Prospector will attempt to answer some of the lingering questions scientists have about the Moon and its history.

MISSION TIMELINE

NOTE: SUBJECT TO CHANGE

Post-Launch Mission Schedule/Timetable

LAUNCH (L) Jan.5,1998(EST)	Lunar Prospector launches from Spaceport Florida aboard Lockheed Martin launch vehicle, the Athena II. This will be the first mission launched from the refurbished Cape Canaveral facility (Launch Complex (Pad) 46), and the second mission to fly aboard an Athena rocket.
L + 13 minutes	Burnout of Athena II. Lunar Prospector is now in a “parking orbit” around the Earth, about 115 miles (185 km) high. It will coast almost halfway around the Earth in 43 minutes before separating from the launch vehicle. Half a second after separation from the Athena, small spin rockets ignite to set the spacecraft spinning at 57 rpm.

L + 56 minutes	STAR 37 kick motor ignites for one minute, setting Lunar Prospector on course for the Moon. For the next 105 hours, the spacecraft doesn’t really "fly" like an airplane. Except for three tiny course corrections en route, it simply coasts to the Moon.
SEPARATION (S) (L +~57 minutes)	This is a critical event in the launch of a spacecraft. It is the moment when the craft itself separates from the STAR 37 (injection stage) and operates under its own power for the first time. Mission timeline begins. Power is turned on to all systems except science instruments.
S + 23 minutes	Spacecraft establishes link with tracking station in California.
S + 43 minutes	Engines aboard Lunar Prospector fire to rotate it sideways with respect to the Earth. The spacecraft is also sideways relative to the sun (only five degrees away from horizontal), which optimizes the amount of energy the solar panels produce.
S + 1:05 minutes	Side engine (thruster) fires to reduce spin rate from 57 rpm to 43 rpm.
S + 1:49 hours	The three 8-foot booms holding the science instruments begin to extend out from the spacecraft. Proper deployment is critical. In an extreme case, if one boom were to completely break off, the spacecraft could tumble out of control. A more likely mishap, however, would be if a single rib (longeron) of one boom broke off; in this case the spacecraft would be able to function normally. As the booms deploy, the spacecraft’s rotation slows down, as a spinning skater would if she extended her arms. The new rotation speed is 9 rpm.
S + 3:05 hours	The spacecraft is spun up to its normal spin rate of 12 rpm.
S + 4:00 hours	Engines fire for the first flight-path correction to trim out any errors in the launch and injection stages.
S + 5:15 hours	The remaining science instrument, the Alpha Particle Spectrometer (APS), is turned on.

S + 1 day, 1:39 hours	The ER, NS and GRS finish their degassing period and begin collecting data, joining the MAG and APS, already collecting data for one day. Since Lunar Prospector is still far from the Moon, this data is used only to calibrate the instruments.
S + 1 day, 4:00 hours	Engines fire for the second flight-path correction and possible re-orientation of the spacecraft. Each burn costs fuel, and may reduce mission lifetime.
S + 2 days, 4:00 hours	Engines fire for the third flight-path correction.
S + 2 days, 4:33 hours	The spacecraft is spun up to 18 rpm and re-oriented 22 degrees in preparation for lunar orbit insertion (LOI).
S + 3 days, 22:31 hours	Lunar Prospector enters the Moon’s sphere of influence, where the pull of the Moon’s gravity begins to overpower that of the Earth.
S + 4 days, 8:16 hours	Engines fire for 31 minutes in an LOI burn as the spacecraft passes within 52 miles (84 km) of the surface of the Moon. The first LOI burn leaves Lunar Prospector in a very elongated, 12-hour orbit. The spacecraft completes two orbits before the second LOI burn.
S + 5 days, 8:15 hours	Engines fire for the second LOI burn. This places Lunar Prospector in a less elongated interim orbit, which takes it around the Moon once every three and a half hours. The spacecraft completes seven orbits before the third burn.
S + 6 days, 8:44 hours	Engines fire for the third and final LOI burn. This places Lunar Prospector in a circular orbit, 62 miles (100 km) above the Moon, completing one revolution every 118 minutes. The orbit goes around the poles, rather than the equator like the Apollo missions, so that Lunar Prospector can map the entire surface as the Moon rotates beneath it.
S + 6 days, 11:58 hours	Engines fire to align the spacecraft horizontally with the sun. This permits solar panels to receive maximum energy, while keeping the Earth within range of Prospector's medium-gain antenna.
S + 6 days, 14:04 hours	Lunar Prospector begins lunar data collection.

S + 4 - 6 weeks	By this time, the Neutron Spectrometer (NS) should be able to confirm or deny the presence of water on the Moon. Water ice, if it exists on the Moon, is in permanently shadowed deep polar craters. Since the spacecraft passes over the poles, collecting polar data with every orbit, this question will be the first of Prospector's science questions that is addressed
Once a month (estimated)	Engines fire to correct the orbit whenever the altitude of the spacecraft drops below about 50 miles (80 km). No one knows exactly how often that will occur -- the estimate of once per month is based on a model of the Moon's gravity derived from data from Apollo and Clementine Lunar missions. A goal of Lunar Prospector is to improve on that model, so that the fuel budget for future lunar missions can be calculated more precisely.
S + 1 year	End of Lunar Prospector's primary mission. Lunar Prospector is expected to have more than enough fuel to continue its work. At the end of the first year, mission controllers will decide on an extended mission plan. Current plans are to descend to a 6 mile (10 km)-high orbit for two months to six months, depending on available fuel.
S + 18 months	Lunar Prospector is expected to run out of fuel, and without corrections to its orbit, the spacecraft will eventually impact the surface of the Moon.
Extended Mission-Impact of Lunar Eclipses	The Lunar Prospector battery has been sized to handle a maximum shadow duration of 47 minutes. Such eclipses can occur in lunar orbit when the spacecraft passes behind the Moon as seen from the sun. Such shadows can occur as often as once an orbit, or every 118 minutes. In addition to these lunar shadows, the possibility also exists for much longer shadows at certain times of the year when the earth passes between the sun and moon at a time when the Moon is crossing through the ecliptic plane (the plane containing the sun and earth) while in its orbit about the earth. This geometry occurs roughly every 6 months, and when the timing is just right, a total eclipse of the Moon can occur which can last several hours. Such a total eclipse is predicted to occur in January 2000, and a partial eclipse is expected in July 1999. While no one knows for sure whether Lunar Prospector would survive such long shadows where the battery would discharge and the temperature of key components would drop below nominal

levels, a launch date was selected such that the nominal one year LP mission would be completed prior to these eclipses.

THE SPACECRAFT

In keeping with the Discovery program's motto of "faster, better, cheaper," the Lunar Prospector spacecraft is small and simple — about the size of a large recycling drum. It will carry a sparse payload of only five instruments, attached to the ends of three 8-foot (2.4-meter) extendable masts. A small group of scientists and aerospace engineers designed and built the spacecraft from existing hardware, a strategy which significantly limited the cost of the overall mission. Several other design features promise to make this trip to the Moon the least expensive one yet, without compromising the focused goals of the mission to return scientific data back to Earth.

A feature that helps to contain mission costs is the absence of an onboard computer. Mission controllers receive data and send commands, and monitor and control the spacecraft, from the ground.
Launch and launch vehicle

Lunar Prospector will be launched first into a low Earth orbit, called a "parking orbit." After circling in this orbit halfway around the Earth, the kick motor of the spacecraft's launch rocket will fire, propelling Prospector toward the Moon. Within a few days, the spacecraft will settle into a circular polar orbiting pattern, circling at 63 miles (100 km) above the surface of the Moon.

The Lunar Prospector launch phase differs slightly from previous missions in that it will employ a relatively simple and inexpensive Lockheed Martin launch vehicle (Athena II). The Athena launch vehicles have been developed for small commercial payloads. At $26 million, the Athena II accounts for nearly half of Lunar Prospector's total mission cost of ~$63 million. It is provided by Lockheed Martin Astronautics, Denver, Colo.

The Athena II is a three-stage rocket. The first two stages consist of Castor 120® solid rocket motors, and the third stage is an Orbus 21D® solid rocket. This launch vehicle is unusually small and inexpensive for a space mission, but perfectly appropriate for the small Lunar Prospector spacecraft, which weighs only 650 pounds (295 kg) with fuel.

The Athena II's Trans Lunar Injection stage (kick motor) is a Star 37 FM motor (Thiokol Corporation, Elkton, Maryland). The kick motor, when ignited, will increase Prospector's speed by 7,000 miles per hour (11,200 km per hour), thrusting the spacecraft out of its parking orbit and toward the Moon. Encased in titanium, the motor houses an igniter which is lit by two flame sticks. The motor is a 5.5 foot (1.7 meter)-long cylinder with a 3-foot (0.9-meter) diameter.

The kick motor is also equipped with spin motors (located outside of the stage). The kick motor is required to propel the Trans Lunar Injection stage and spacecraft into space.

Lunar Prospector is scheduled for launch from Spaceport Florida's Complex 46 (Cape Canaveral, Florida) on Jan. 5, 1998. One of the primary reasons mission designers chose this launch window is its proximity to an unusually long period of time without any total lunar eclipses. During a total lunar eclipse, the Earth passes between the Sun and the Moon, shadowing the entire Moon from the perspective of the Earth. During a lunar eclipse, Prospector would have to fly in total darkness and consume additional battery power. Prospector's launch date allows the spacecraft to spend as little time as possible in Earth's shadow, minimizing battery power drain and spacecraft cooling requirements.

The Vehicle

Like all Discovery missions, Prospector progressed rapidly from development to completion and testing phases — the entire construction process was accomplished in a period of only 22 months. One feature that expedited this process was the fact that many parts of the spacecraft and its accompanying instruments were manufactured from "off-the-shelf," flight-proven hardware. Lunar Prospector rotates around its own central axis in order to control its orientation en route to the Moon. From an engineering perspective, a spin-stabilized spacecraft like Prospector is inherently more simple (and cheaper) to design.

By purposeful design, Lunar Prospector (and its instruments) are low mass and low power. The spacecraft is constructed of a graphite epoxy material: a lightweight and sturdy substance. When stocked with fuel, it weighs only 650 pounds (295 kg) — less than 20 percent the weight of a medium-sized car. The spacecraft contains six thrusters (small engines) — two are oriented upward, two are oriented downward, and two extend outward sideways from the spacecraft. The six engines are used to control the spacecraft's spin rate, velocity and attitude (relative position in space).

With its three booms retracted, Prospector's shape is that of a cylindrical drum, 4.25 feet (1.3 meters) tall and 4.5 feet (1.4 meters) in diameter. Two antennae (an omni antenna and a medium-gain antenna) positioned atop one another, resemble an enlarged white traffic cone that juts upward approximately three feet from the top of the spacecraft. From the outside, Lunar Prospector has an almost jewel-like appearance — its nearly 3,000 small blue rectangular solar panels glimmer like the facets of a blue sapphire.

Deployable 8-foot (2.5-meter) masts, or booms, contain the spacecraft's payload of five instruments: the neutron spectrometer, gamma ray spectrometer, alpha particle spectrometer, and magnetometer/electron reflectometer. The booms deploy very much like springs unwinding. When mission controllers provide the command, a small device called a “paraffin actuator” heats up and melts a wax seal that releases the booms.

Prospector’s booms do more than just house the instruments — an important function of the booms is to keep those instruments at an extended distance. One instrument, the magnetometer, is even sensitive to its own electronics: an additional boom extension places this instrument as far out as possible from the body of the spacecraft to minimize potential interference. Alternately wrapped in shiny copper and silver-colored reflective components, this mini-boom resembles a barbershop pole. Together, the ribbon-like wrapping components provide thermal control by alternately reflecting and absorbing heat.

Spacecraft subsystems

Fuel (propellant)

Lunar Prospector contains enough fuel to perform its one-year primary mission as well as an extended mission, in which an engine burn may thrust the spacecraft into a much closer orbit, just a few miles above the lunar surface. Current estimates suggest that the extended mission, lower-orbit phase will continue for approximately six months (after the first year), until the spacecraft’s fuel runs out and the vehicle impacts the Moon, ending the mission.

Prospector is fueled by a simple, monopropellant propulsion subsystem. Three helium-pressurized titanium tanks of hydrazine will propel Prospector into orbit, maintain its orbit, and provide spin control for the rotating spacecraft. Prospector’s hydrazine tanks and fuel lines are temperature-controlled by heaters, so that the liquid hydrazine never freezes or boils, remaining between 39°F (4°C) and 100°F (38°C). Engine and tank temperatures, as well as tank pressures, are downlinked to mission controllers on the ground via the spacecraft’s communications system.

Power

Lunar Prospector is solar cell-powered and has a rechargeable nickel-cadmium battery. The solar array, comprising nearly 3,000 individual solar cells, provides 202 watts of power to the spacecraft and its five instruments. During daylight, Prospector’s batteries will be continually recharged by the Sun, so that it has enough power to operate at night, in the dark.

Lunar Prospector’s magnetometer is very sensitive to interference from stray magnetic fields. Several features of the solar array were designed to minimize such interferences: the solar array is cylindrical in shape, the wiring is routed so as to cancel magnetic fields, and all wires are twisted together.

Attitude control

Lunar Prospector’s attitude (relative position in space) is controlled by the firing of the spacecraft’s thrusters (engines). Basically, the spacecraft’s thrusters fire in pairs to change the spacecraft’s orientation and maneuver it through space. Prospector’s Sun and Earth/Moon sensors tell the ground crew where the spacecraft is located in relation to the Sun, the Earth, and the Moon. This information helps pinpoint Prospector's position and enables mission controllers on the ground to follow the spacecraft and keep it properly oriented.

Communications

The spacecraft has two antennae (a medium-gain antenna and an omni antenna) which together sit atop the spinning spacecraft. Mission controllers will use the omni antenna while Prospector is en route to the Moon, and then they will switch to the medium-gain antenna while the spacecraft flies in lunar orbit. Commands will be up-linked (omni) and data will be down-linked (medium-gain) via an S-Band transmitter and an S-Band receiver, using NASA's Deep Space Network as a tracking system.

Lunar Prospector does not have an onboard computer. A simple electronics box, called the Command and Data Handling Unit, accepts a maximum of 60 commands from Earth.

SCIENTIFIC OBJECTIVES

Lunar Crustal Magnetism

Using data obtained both from its **Magnetometer and Electron Reflectometer** (Mag/Er) instruments, Lunar Prospector will correlate magnetic anomalies with surface geology.

By mapping the global locations, strengths and orientations of lunar crustal magnetic fields, scientists can learn more about the relationship between such magnetic fields and the surface geology. For example, scientists believe that certain lunar surface features, such as the albedo swirls, may have magnetic origins. The swirls resemble unstirred cream in a coffee cup — researchers suspect that the contrasting light and dark regions might indicate the juxtaposition of irregular magnetic fields.

Compared to the Earth, the Moon has a very small magnetic field. While some of the Moon's magnetism is thought to be intrinsic (such as a strip of the lunar crust called the Rima Sirsalis), collision with other celestial bodies might have imparted some of the Moon's magnetic properties in places. Indeed, a long-standing question in planetary science is whether an airless solar system body, such as the Moon, can obtain magnetism from impact processes such as comets and asteroids.

Magnetic measurements can also supply information about the size and electrical conductivity of the lunar core — evidence that will help scientists better understand the Moon’s origins. For instance, if the core contains more magnetic elements (such as iron) than the Earth, then the impact theory loses some credibility (although there are alternate explanations for why the lunar core might contain less iron).

Crustal Composition, Volcanism and Polar Ice

Lunar Prospector will use its Neutron Spectrometer and Gamma Ray Spectrometer to determine the bulk elemental composition of the Moon as well as to identify potential lunar resources, including water ice (in the permanently shadowed poles).

Water ice — Over time, comets and meteorites continually bombard the Moon. Water-rich meteorites and comets, largely water ice, may leave significant traces of water on the lunar surface. Energy from sunlight splits much of this water into its constituent elements hydrogen and oxygen, both of which usually fly off into space immediately. Some water molecules, however, may have literally hopped along the surface and gotten trapped inside enormous craters —some 1,400 miles (2,240 km) across and nearly 8 miles (13 km) deep — at the lunar poles. Due to the very slight “tilt” of the Moon’s axis, only 1.5°, some of these deep craters never receive any light from the Sun — they are permanently shadowed. It is in such craters that scientists expect to find frozen water if it is there at all. If found, water ice could be mined and then split into hydrogen and oxygen by solar panel-equipped electric power stations. Such components could make space operations as well as human colonization on the Moon possible.

Although Moon rock collected by Apollo astronauts in the equatorial region contained no traces of water, the recent Clementine mission suggested that small, frozen pockets of water ice (remnants of water-rich comet impacts) may be embedded unmelted in the permanently shadowed regions of the lunar crust. Although the pockets are thought to be small and well-mixed with rock, the overall amount of water was suggested to be quite significant — one billion cubic meters, or an amount the size of Lake Erie. The presence of usable quantities of water on the Moon would be an important factor in rendering lunar habitation cost-effective, since transporting water (or hydrogen and oxygen) from Earth would be prohibitively expensive.

KREEP — More than four and a half billion years ago, it is thought that the surface of the Moon was a liquid magma ocean. Scientists think that one component of lunar rocks, KREEP (K-potassium, Rare Earth Elements, and P-phosphorous), represents the last chemical remnant of that magma ocean. KREEP is actually a composite of what scientists term “incompatible elements”: those which cannot fit into a crystal structure and thus were left behind, floating to the surface of the magma. For researchers, KREEP is a convenient tracer, useful for reporting the story of the volcanic history of the lunar crust and chronicling the frequency of impacts by comets and other celestial bodies.

Primary elements — The lunar crust is composed of a variety of primary elements, including uranium, thorium, potassium, oxygen, silicon, magnesium, iron, titanium, calcium, aluminum and hydrogen. When bombarded by cosmic rays, each element bounces back its own radiation, in the form of gamma rays, into space. Some elements, such as uranium, thorium and potassium, are radioactive and emit gamma rays on their own. However, regardless of what causes them, gamma rays for each element are all different from one another — each produces a unique spectral "signature," detectable by an instrument called a spectrometer. A complete global mapping of the Moon for the abundance of these elements has never been performed.

Scientists call uranium, potassium and thorium "refractory elements." These particular refractory elements are radioactive and naturally produce their own gamma rays. Heat produced as a result of this radioactivity warms not only the insides of the Moon, but is responsible for the long-term warming of the Earth's interior as well.

Hydrogen and helium — Since its surface is not protected by an atmosphere, the Moon is constantly exposed to solar wind, which carries both hydrogen and helium — each potentially very valuable resources. One natural variant of helium, helium-3, is the ideal material to fuel fusion reactions. When scientists develop a more thorough understanding of fusion, and can practically implement such reactions, the Moon will be a priceless resource, since it is by far the best source of helium-3 anywhere in the Solar System.

Crustal Structure

Lunar Prospector's Doppler Gravity Experiment will improve the resolution of existing crustal asymmetry data.

Lying on top of the Moon's crust is a ground-up rock layer called regolith. The crust is uneven over the entire Moon's surface. The crust ranges from 38 miles (60 km) on the near side to 63 miles (100 km) on the far side. Scientists think that such asymmetry of the lunar crust most likely accounts for the Moon's offset center of mass. Crustal asymmetry may also explain differences in lunar terrain, such as the dominance of smooth rock (maria) on the near side of the Moon. The regolith varies from 10 to 16 feet (3 to 5 meters) in the maria to 33 to 66 feet (10 to 20 meters) in the highlands. Scientists think that the variations in thickness of the regolith is directly related to the age of the surface.

High-resolution gravity data permits scientists to determine the density of the lunar core as well as other density variations in the interior. This is important information for designing fuel-efficient future lunar missions and landing operations.

Outgassing Sources of the Lunar Atmosphere

With its Alpha Particle Spectrometer, Lunar Prospector will determine whether the outgassing of nitrogen, carbon monoxide and carbon dioxide is related to tectonic activity. In addition, it will determine the resource potential of each particular gas.

The Moon has a relatively insignificant and tenuous atmosphere. One source of this atmosphere is outgassing — the release of gases, for instance radon, which originate deep within the Moon's interior. Compared to the Earth, the Moon is tectonically inactive; however, moonquakes do occur. By measuring outgassing events, researchers may also be able to infer information about the character and frequency of that tectonic activity.

When and where gases are emitted tells scientists how the thin lunar atmosphere is likely formed. Certain elements, such as uranium and thorium, are radioactive — over time, these elements lose energy and decay into new elements, such as radon and polonium. The energy lost, in the form of gamma rays, alpha particles and beta particles, can be measured by special detectors called spectrometers. Each is a different kind of "time machine" that scientists can use to determine what happened on the Moon days, months, even decades in the past. More abundant gases, such as nitrogen and carbon dioxide and carbon monoxide, are also outgassed along with radon. Knowing when and where lunar outgassing of these gases takes place is important for potential resource utilization.

SCIENTIFIC INSTRUMENTS

Lunar Prospector will study the Moon's composition using proven technology. The instruments on Lunar Prospector represent the next generation of the same devices that have flown aboard Apollo and other missions.

Prospector's scientific instrument team is made up of three groups. Dr. William Feldman (Los Alamos National Laboratory, Los Alamos, NM), G. Scott Hubbard (NASA Ames Research Center, Moffett Field, CA) and Dr. Alan Binder (Lunar Research Institute, Gilroy, CA) make up the spectrometer group, which oversees operations of the neutron, gamma ray and alpha particle spectrometers. Dr. Lon Hood (University of Arizona, Tucson, AZ) and Dr. Robert Lin (University of California at Berkeley) make up the magnetometer group. Dr. Alexander Konopliv (Jet Propulsion Laboratory, Pasadena, CA) heads the gravity group.

Neutron Spectrometer

The Neutron Spectrometer (NS) may be the “star of the show” in the first few weeks of the Lunar Prospector mission. This instrument will search for water ice -- specifically, by detecting the element hydrogen on the Moon's surface. Since every water molecule contains two atoms of hydrogen and one of oxygen, hydrogen is a good marker for water. Traces of hydrogen could also be implanted in the Moon's surface by the solar wind. But if water is present in usable quantities, the amount of hydrogen locked up in water molecules will dwarf the amount that is present for other reasons.

In 1994, the Department of Defense satellite Clementine probed the Moon's surface with radar. The radar signals that bounced back from the deep, permanently shadowed craters near the Moon's poles were consistent with water ice being there. However, there could be other explanations for Clementine's observations. The NS will give a clear and definite answer to the question of whether water exists in usable quantities at the poles. Even if only 0.5 percent of the surface material at a given location is water, Lunar Prospector will be able to find it. To put it another way, the NS could detect a cup of water in a cubic yard of soil.

The NS will not detect hydrogen directly, since it will be 63 miles (100 km) above the Moon's surface. Instead, it will look for what scientists call “cool” neutrons -- neutrons that have bounced off a hydrogen atom somewhere on the lunar surface. When cosmic rays collide with atoms in the crust, they violently dislodge neutrons and other subatomic particles, such as gamma rays. Some of the neutrons escape directly to space, as hot or “fast” neutrons. Other neutrons shoot off into the crust, where they collide with other atoms, bouncing around like pinballs. If they only run into heavy atoms, they do not lose very much energy in the collisions, and are still traveling at close to their original speed when they finally bounce off into outer space. They will still be warm (or “epithermal”) when they reach Lunar Prospector and are recorded by the NS.

The only effective way to slow down a speeding neutron is to have it collide with something its own size. (The same is true with a pinball: if it runs head on into a stationary pinball, it will come to a dead stop. If the collision is not quite head on, it will slow down dramatically.) There's only one atom the same size as a neutron: hydrogen, the lightest of all the elements. If the Moon's crust contains a lot of hydrogen at a certain location -- say, a crater with water in it -- any neutron that bounces around in the crust before heading out to space will cool off rapidly. When Lunar Prospector flies over such a crater, the NS will detect a surge in the number of cool (“thermal”) neutrons, and a dropoff in the number of warm (“epithermal”) neutrons.

The NS has two different counters -- a cadmium-wrapped canister of helium-3 and a tin-wrapped canister of helium-3. When a neutron collides with an atom of helium-3, a nuclear reaction takes place, producing a burst of energy. That burst of energy tells scientists that they have detected a neutron.

Except for the outside wrapping, the two counters are nearly identical. The cadmium-wrapped counter detects only the epithermal neutrons, because cadmium is good at screening away the slow-moving thermal neutrons, whereas the tin-wrapped counter lets all of the neutrons through. Since the two counters are otherwise identical, any difference between the two must be attributable to thermal neutrons. Lunar Prospector will measure epithermal neutron flux with a separate instrument (its gamma ray spectrometer). The respective count rates of the different types of neutron fluxes are an indicator of hydrogen content, and hence the presence of water ice, embedded within the lunar soil. Soil containing ice, for instance, should yield a higher thermal neutron flux and a lower epithermal neutron flux than soil devoid of ice.

As scientists receive data from the spacecraft, their screens will be updated with new neutron counts twice per second, and new energy spectra (showing the speed of the captured neutrons) will appear every 32 seconds. Since the data will have a lot of random noise in it, several passes over the surface and careful statistical analysis may be required to reduce the uncertainty to the point where scientists can be sure they have found water. However, there is one factor working in the scientists' favor: the spacecraft will pass over the poles every orbit, while it passes over any given region on the equator only a few times a month. Thus the NS will produce more accurate data in the polar regions -- precisely where the water is thought to be. If water is present in the amounts suggested by the Clementine mission, the NS should be able to detect it, possibly within a month.

* The Neutron Spectrometer weighs 8.5 pounds (3.9 kilograms), consumes 2.5 watts of power and produces 49 bits of data per second. It will be deployed together with the Alpha Particle Spectrometer at the end of one of the spacecraft's three booms.

Gamma Ray Spectrometer

The Gamma Ray Spectrometer (GRS) will map the abundances of ten elements on the Moon's surface: thorium, potassium, uranium, iron, oxygen, silicon, aluminum, calcium, magnesium, and titanium. It will be especially sensitive to the heavy, radioactive element thorium and the light element potassium. These are particularly plentiful in the Moon's youngest rocks, the last part of the crust to solidify. The data produced by the GRS will help scientists understand the origins of the Lunar landscape, and may also tell future explorers where to find useful metals like aluminum.

A gamma ray is a very energetic photon (a tiny parcel of light) -- more energetic than a visible light ray or an X-ray. The gamma rays that the spectrometer will detect come from two sources. "Natural" gamma rays are emitted spontaneously by radioactive elements like thorium and uranium. "Induced" gamma rays are emitted by elements like iron, silicon, and oxygen on the Moon's surface when they are bombarded by cosmic rays. The energy of a gamma ray serves as a distinctive signature of the atom that emits it.

When the gamma rays hit Lunar Prospector, they will pass through a crystal of bismuth germanate in the GRS. The bismuth atoms give off a flash of light when the radiation hits them; the more intense the gamma ray is, the brighter the flash. The energy of a gamma ray, in turn, tells researchers exactly which kind of atom emitted it.

The GRS will also contribute indirectly to the search for water on the Moon. The bismuth germanate crystal is surrounded by a shield of borated plastic that will detect epithermal neutrons.

The gamma ray energy spectrum has a lot of “noise” in it, due to gamma rays that collide with other atoms in the Moon's crust. Unlike the NS, the GRS will search for gamma rays that have escaped straight into space, because those are the ones that carry the telltale atomic signatures. Because of the uncertainty in these counts, one sweep over the Moon's surface would not give scientists enough information to determine the concentration of the radioactive elements. In addition, the stable elements do not emit gamma rays as readily as the naturally radioactive ones, so it will take Lunar Prospector up to a year or more to collect enough data to estimate their concentrations.

Lunar Prospector will pass over each “resolution element” -- that is, each 94-mile (150-kilometer) by 94-mile (150-kilometer) area on the Moon's surface -- about nine times per month (more frequently for polar regions). As they receive more data, scientists will be able to reduce the errors due to random noise or small numbers of gamma rays, using statistical analysis. In approximately three months, they should be able to generate useful estimates of the abundance of thorium and potassium. For aluminum, calcium, and magnesium, it may take up to the full 12 months.

* The Gamma Ray Spectrometer weighs 19 pounds (8.6 kilograms), uses 3 watts of power, and produces data at a rate of 688 bits per second. It will be deployed on one of Lunar Prospector's three booms.

Alpha Particle Spectrometer

Prospector's Alpha Particle Spectrometer (APS) will detect alpha particles emitted by radioactive gases, such as radon and polonium, leaking out of the lunar interior. While the Moon currently lacks volcanoes, it does appear to vent gases such as radon , nitrogen, and carbon dioxide. The APS will search for these outgassing events by detecting alpha particles.

An alpha particle is essentially the nucleus of a helium atom: two protons and two neutrons bound together. Like gamma rays, alpha particles escape from radioactive elements as part of their natural decay process. The alpha particles are emitted with a precise energy that serves as a fingerprint for the atom from which they came.

Inside the APS are ten separate wafers of silicon. Silicon, a semiconductive material, conducts electrical charge only minimally. For that reason, however, it produces a high-resolution signal, since it effectively blocks out most extraneous, background charge. When an alpha particle hits a silicon wafer, it creates a small track of charge. When a high voltage is applied to the silicon wafer, the alpha particle's charge is funneled into an amplifier (an aluminum disk atop the silicon), where it is collected. Since that pulse of charge is directly proportional to the signature energy of the alpha particle, scientists can infer the identity of the element which emitted the alpha particle.

The APS instrument contains ten such silicon detectors, each sandwiched between gold and aluminum disks, and arranged on five out of six sides of a cube, enabling nearly a complete field of detection.

The detection of gases will depend very much on whether any outgassing events occur while Lunar Prospector is in orbit, and how many there are. Of course, the longer the mission lasts, the more events scientists are likely to see. Also, because the outgassing events are localized, the precision of the data will improve considerably if, as currently planned, Lunar Prospector has enough fuel after the first year to drop to a lower orbit 6 miles above the surface. (For a rough terrestrial analogy, from the higher orbit Lunar Prospector would be able to say that a volcano has erupted in the state of Washington. From the lower orbit, it would be able to say which volcano.)

* The Alpha Particle Spectrometer weighs 9 pounds (4 kilograms), consumes 7 watts of power and produces data at a rate of 181 bits per second.

Magnetometer/Electron Reflectometer

The Magnetometer (MAG) and Electron Reflectometer (ER) will determine the magnetic field strength in the vicinity of the spacecraft and at the Lunar surface, respectively. Researchers will be able to compare these measurements to determine whether magnetic field variations are caused by surface features or by the Moon's core.

Magnetometer

The magnetic fields measured by the MAG will be a combination of the Earth's magnetic field (35,000 nano Teslas), the field carried from the Sun by the solar wind (approximately 10 nano Teslas), and the Moon's field, which is extremely weak (approximately 1,000 nano Teslas) compared to that of the Earth. The magnetic field at the lunar surface is also affected by local deposits of magnetic material.

The instruments are copies of detectors that are on board the Mars Global Surveyor spacecraft, launched in December 1996, with some modifications to adapt them for a spinning spacecraft. The triaxial fluxgate magnetometer is a standard device that is also used to measure magnetic fields on Earth. “Triaxial” means that it includes sensors to measure the strength of the field in three different directions. This enables scientists to determine not only the maximum strength of the field but also the direction it points. The “fluxgate” is an electric coil through which the magnetic field passes. By measuring the variation of the current passing through the coil, the MAG determines the strength of the magnetic field. It can measure magnetic fields as weak as one-millionth of the strength of the Earth's magnetic field.

* The Magnetometer is mounted on a boom 8.5 feet (2.6 meters) away from the spacecraft, in order to isolate it from the magnetic fields generated by the spacecraft's own electronics.

Electron Reflectometer

The ER, unlike the MAG, is a remote instrument: it will measure the magnetic field at the surface of the Moon. Together, the two instruments will able to detect local variations in the Moon's magnetic field that arise from selenological features on the Lunar surface. The key to measuring the magnetic field from 63 miles (100 km) away is a scientific trick that was first used successfully on the Apollo 15 and 16 missions.

The Moon, like every other body in the Solar System, is constantly barraged by electrons from the Solar wind. (On Earth, a few of the electrons make it into the upper atmosphere, where they contribute to phenomena such as the Van Allen radiation belts and the Aurora Borealis. Most of them, however, are repelled by the Earth's magnetic field.) Unlike the Earth, the Moon does not have a magnetic field strong enough to repel these tiny charged particles, and so they spiral toward the surface in giant loops, typically several miles wide. The electrons that descend in a tighter spiral make it to the surface of the Moon and are absorbed there. But if there is magnetic material on the Moon, it will reflect some of the electrons back into space.

When the reflected electrons reach the Lunar Prospector spacecraft, the ER will measure their pitch angle. After the pitch angles of many electrons are tabulated, scientists will see an abrupt cutoff above a certain angle -- because all the electrons with a larger pitch angle were absorbed by the Moon. That cutoff tells the researchers just how intense the magnetic field was at the lunar surface.

* The Electron Reflectometer is linked to the Magnetometer by a smaller, 2.5-foot (0.8 meter) boom; the assembly when fully deployed resembles an elbow with a 90° bend. The combined weight of the Magnetometer and Electron Reflectometer is about 11 pounds (5 kilograms). Together, the two instruments use 4.5 watts of power, and produce 670 bits of data per second.

Doppler Gravity Experiment

The Doppler Gravity Experiment (DGE) will improve the best current models of the Moon’s gravitational field, enabling future lunar missions to use fuel more efficiently.

The Moon has a much “bumpier” gravitational field than the earth, with small anomalies due to mass concentrations (or “mascons”) on the surface, and a large asymmetry due to the fact that the crust is thicker on the far side of the Moon. These bumps cause an orbiting spacecraft to speed up or slow down. The DGE will, in effect, draw a map of the bumps.

The DGE, unlike the other experiments aboard Lunar Prospector, requires no extra instrumentation. All of the data is collected simply by communicating with the spacecraft. As the spacecraft orbits the Moon, its speed can always be determined by the Doppler effect, the same effect that causes a police siren to sound higher when the police car is moving toward you and lower when it is moving away from you. The “siren,” in this case, is the spacecraft's radio signal, whose frequency shifts slightly as it moves toward Earth or away from it.

By tracking the velocity of the spacecraft, mission scientists can infer the forces acting upon it. For over 99 percent of the duration of the mission (excepting only periods when the engines are being fired) the only force on Lunar Prospector will be gravity. Thus, by simply circling the Moon and sending signals back to Earth, Lunar Prospector will map the Moon's gravitational field. Lunar Prospector will complete its gravitational map in two months. However, the results of the DGE will be greatly improved if the mission extends beyond the first year. Plans for the extended mission, which will last from the end of the first year to whenever the spacecraft runs out of fuel, call for the spacecraft to descend to an altitude of 30 miles (48 km) and then 6 miles (10 km). At an altitude of 6 miles (10 km), the precision of the gravity data will be improved by a factor of over 100.

DISCOVERY PROGRAM

Lunar Prospector is the first peer-reviewed competitively selected Discovery mission and the third to launch. The program's motto, “faster, better, cheaper,” was born of current NASA Administrator Daniel Goldin's vision for a more streamlined approach to exploring space in a lean, post-Cold War economy. The Discovery program strikes a balance between implementing new technologies and paying careful attention to cost containment. The requirement to develop an entire Discovery mission in three or less years is designed to promote the use of the most recent, up-to-date technology. Finally, a key component of the Discovery program is public awareness -- each mission aims to increase appreciation for space exploration through educational outreach activities.

The program's philosophy is a departure from the style of planetary exploration initiated by the agency in the 1960s. Previous missions, such as Apollo, were the outcome of many years of work conducted by large groups of scientists, administrators, and astronauts. Such missions had price tags of a billion or more dollars, since they resulted from NASA soliciting independent, competitive bids for each separate aspect of the mission -- operations, scientific investigations, the spacecraft itself and so on. Instead, the Discovery program solicits proposals encompassing all aspects of a mission, the goal being focused science achieved through smaller, more frequent missions.

The cornerstone of the Discovery program is the idea that NASA is "buying a mission from the Principal Investigator" (the Principal Investigator is the scientist in charge of the project). In contrast to past NASA missions, such a strategy places significantly more responsibility with the PI, and encourages that the maximum amount of science is returned for each dollar spent. Each Discovery mission is required to cost less than $150 million to develop (based on 1992 dollars); the Lunar Prospector mission is particularly inexpensive, with a total mission cost of only $63 million. Inherent budget constraints of Discovery projects do require substantive trade-offs, such as fewer instruments; however, the strategy also offers unexpected pluses.

Redundancy of components is a good example. Past NASA-sponsored missions, especially ones with humans aboard, contained multiple backup parts, sometimes enough to constitute two or more duplicate spacecrafts. Lunar Prospector has minimal redundancy. And spacecraft like Prospector, which are simple by design, may be less prone to technical failure because there are fewer overall components. Due to lower cost, entirely new missions can potentially be designed and implemented for the same cost of developing and manufacturing duplicate or triplicate parts.

Current Discovery Missions

To date, current Discovery missions, either in progress or still in the development stages, are set to explore Mars (Mars Pathfinder), asteroid 433 Eros (NEAR), the Moon (Lunar Prospector) and the exterior of an active comet (Stardust). The star, planet or moon of our Solar System that will be the next subject of focused scientific study -- the next Discovery mission -- has just been selected from a group of proposals spanning a wide range of scientific objectives. The proposal committee chose from five potential missions: Messenger (a Mercury orbiter), Vesat (a Venus orbiter), Aladdin (sample return from Martian moons Phobos and Deimos), Contour (a comet fly-by), and Genesis (solar wind sample return). Genesis and Contour were selected. The next request for proposals will be distributed shortly thereafter, with selection targeted for the spring of 1998.

Near Earth Asteroid Rendezvous (NEAR)

NEAR, launched in 1996, is to rendezvous with asteroid 433 Eros on February 6, 1999. NEAR will be the first spacecraft to orbit an asteroid. It is designed to provide scientists with data to answer fundamental questions about near-earth objects such as asteroids and comets -- what they are made of and where they came from.

Mars Pathfinder

Mars Pathfinder was launched December 4, 1996 and operated successfully on the surface of Mars for several months. Pathfinder's goals were to study the Martian atmosphere, surface meteorology and areology (analogous to the Earth's "geo"-logy), and elemental composition of the rocks and soil.

Lunar Prospector

Lunar Prospector, NASA's first peer-reviewed competitively selected Discovery mission but the third to launch, will rediscover the Moon. It will circle the Moon in a polar orbit, 63 miles above the lunar surface, for a period of one year and is expected to return answers to long-standing questions about the Moon's resources, structure and history. Among Prospector's capabilities is its ability to confirm or refute the existence of water ice tucked away in pockets of the sun-deprived lunar poles.

Stardust

Stardust is scheduled for launch in early 1999. Stardust's primary aims are to gather dust grains between stars and to collect (and return to Earth) samples of material surrounding the active comet Wild-2.

SCIENTISTS' BIOGRAPHIES

Dr. Alan Binder (Lunar Research Institute, Gilroy, CA)

Dr. Alan Binder is Principal Investigator for the Lunar Prospector mission. He is also responsible for the Alpha Particle Spectrometer instrument on board the spacecraft, as part of the Spectrometer Group (headed by Dr. William Feldman). Dr. Binder earned a bachelor's degree in physics in 1961 from Northern Illinois University, and in 1967, earned a doctorate in geology and lunar and planetary science from the University of Arizona's Lunar and Planetary Laboratory. His main research interests center around the origin, petrological and structural evolution of the Moon, as well as its possible economic utilization. Dr. Binder has 35 years of experience in the fields of planetary astronomy and planetary geosciences. He was a Principal Investigator on the 1976 Viking Mars Lander Camera Team. For 10 years, he both taught and conducted lunar research in Germany and served as an advisor to the European Space Agency in its studies of a lunar polar orbiter mission. While in Germany, Dr. Binder also developed the proposed German and American lunar exploration program, "Selene," which was to be a series of lunar landers used to set up a geophysical station network and return samples to Earth. Selene was the forerunner to NASA's proposed Common Lunar Lander (Artemis), a project on which Dr. Binder also worked. He has authored or coauthored some 60 scientific papers, mainly in the areas of lunar and Mars geology, geochemistry, petrology and geophysics.

Dr. Mario Acuna (Goddard Space Flight Center, Greenbelt, MD)

Dr. Mario Acuña is a Co-Investigator for the Lunar Prospector mission, responsible (along with Dr. Lon Hood) for the spacecraft's Magnetometer instrument. Dr. Acuña was born in 1940, in Cordoba, Argentina, from where he later received his undergraduate degree at the University there. He went on to receive an MSEE degree in 1967, from the University of Tucuman and then a doctorate in space science from the Catholic University of America, in Washington, D.C., in 1974. From 1963 to 1967, Dr. Acuña worked for the department of electrical engineering and the Ionospheric Research Laboratory at the University of Tucuman, as well as for the Argentine National Space Research Commission. These research activities included several cooperative sounding rocket programs with NASA's Goddard Space Flight Center involving both U.S. and South American scientists, X-ray research with high-altitude balloons and meteorological tracking stations. In 1967, he joined the Fairchild-Hiller Corporation in Germantown, Maryland, to provide engineering and scientific support services to NASA; he became head of the Electronic Systems Division in 1968. Since 1969, Dr. Acuña has been associated with NASA's Goddard Space Flight Center in Greenbelt, Maryland, where his research interests have centered around experimental investigations of the magnetic fields and plasmas in the Solar System. He has participated in several planetary missions, including the Explorers 47 and 50 missions, Mariner 10, Pioneer 11, Voyagers 1 and 2, MAGSAT, Project Firewheel (Germany, Canada, United States and United Kingdom), Viking (Sweden), the Active Magnetospheric Particle Tracer Explorers (AMPTE: Germany, United States, United Kingdom), The International Solar Polar Mission and the GIOTTO mission (ESA) to comet Halley. In 1986, he was selected as the Principal Investigator for the Mars Observer Magnetic Field Investigation (launched in 1992) and is currently in charge of the Mars Global Surveyor spacecraft's magnetometer. Dr. Acuña has published more than 60 research articles, mainly in the field of planetary magnetism.

Dr. William Feldman (Los Alamos National Laboratory, Los Alamos, NM)

Dr. William Feldman is a Co-Investigator for the Lunar Prospector mission and serves as the Spectrometer Group Leader, overseeing the operation of three of the spacecraft's instruments: the neutron spectrometer, gamma ray spectrometer and alpha particle spectrometer. Dr. Feldman was born in 1940. He received a bachelor's degree in physics from the Massachusetts Institute of Technology in 1961 and later earned a doctorate in nuclear structure from Stanford University, in 1968. He has 17 years of experience in analyzing and interpreting solar wind and magnetospheric data. He has participated in the design of seven plasma experiments and an energetic electron dosimeter. Dr. Feldman was the Principal Investigator on a total-absorption neutron spectrometer rocket experiment and a fast neutron spectrometer launched aboard the Naval Research Laboratory LAEC spacecraft. He was also a Co-Investigator on a variety of missions, including Pioneer 10 and 11, IMP 6, 7 and 8, ISEE 1,2 and 3, Mariner 10, Giotto JPA and the Ulysses Space Plasma Physics Experiments. Dr. Feldman was also a member of the Mars Observer Gamma Ray Spectrometer Team, with responsibility for the neutron sensor/charged particle anti-coincidence shield and is chairman of the Solar Probe Science Study Team. He has authored or coauthored more than 180 scientific papers.

Dr. Lon Hood (University of Arizona, Tucson, AZ)

Dr. Lon Hood is a Co-Investigator for the Lunar Prospector mission, responsible (along with Dr. Mario Acuña) for the spacecraft's Magnetometer instrument. Dr. Hood was born in Marshall, Texas in 1949, and received a bachelor's degree in physics in 1971 from Northeast Louisiana University. He later earned a doctorate in geophysics and space physics from the University of California, Los Angeles, where he studied mapping and interpretation of lunar crustal magnetic anomalies using the Apollo 15 and 16 subsatellite magnetometers. Dr. Hood is presently a staff member of the Lunar and Planetary Laboratory at the University of Arizona, where his research for the past several years has focused on theoretical and observational studies of lunar magnetism, outer planet magnetospheres and the terrestrial middle atmosphere. He has served on a number of NASA committees on the Moon and asteroids and has authored or coauthored some 60 scientific papers and two book chapters.

Mr. G. Scott Hubbard (NASA Ames Research Center, Moffett Field, CA)

Mr. Scott Hubbard is NASA mission manager for Lunar Prospector and also a Co-Investigator, responsible for the spacecraft's Gamma Ray Spectrometer instrument. Mr. Hubbard received a bachelor's degree in physics from Vanderbilt University in 1970 and has done graduate work at the University of California, Berkeley. He is the originator of the Mars Pathfinder (formerly MESUR) mission. He is currently Deputy Director of Space at NASA Ames Research Center, where he supervises studies, hardware development and mission operations on such missions as Pioneer and the Galileo Probe. Mr. Hubbard has also contributed experimental hardware to numerous ionizing radiation investigations, including balloon experiments, Apollo-Soyuz and HEAO-Cand ISEE-3. While at Lawrence Berkeley Laboratory, he developed the first thin-window germanium charged-particle telescope, as well as basic technology for ultra-pure germanium gamma ray devices and for far infrared photoconductors. Before coming to Ames, Mr. Hubbard was General Manager for Canberra Semiconductor, and a Senior Research Physicist at SRI International. He has received numerous honors, including NASA's Exceptional Achievement Medal and is the author of more than 30 papers on radiation detection and space missions.

Dr. Alexander Konopliv (Jet Propulsion Laboratory, Pasadena, CA)

Dr. Alexander Konopliv is a Co-Investigator for the Lunar Prospector mission, responsible for the Doppler Gravity Experiment, which will use the spacecraft's telemetry data to measure the Moon's gravitational fields. Dr. Konopliv was born in Minneapolis, Minnesota in 1960 and received a bachelor's degree in aerospace engineering and mechanics from the University of Minnesota in 1982. In that same year, he received a master's degree in aerospace engineering from the Massachusetts Institute of Technology, and in 1986, he earned a doctorate in aerospace engineering from the University of Texas at Austin. Dr. Konopliv has been involved in planetary gravity analysis since 1991 as a member of the Planetary Gravity Analysis Group in the Navigation Systems Section of the Jet Propulsion Laboratory. Currently, he is processing the Magellan Doppler tracking data and combining it with the Pioneer Venus Orbiter tracking data to produce a 75th degree and order spherical harmonic gravity field model. This high resolution gravity field model will be made available to the Magellan science team for geophysical investigation. Dr. Konopliv's work on the lunar gravity field from the reduction of Apollo and Lunar Orbiter data provides the basis for determining the lunar orbit maintenance requirements for Lunar Prospector. This gravity field model was also used by the Clementine mission during operations for real-time orbit determination of the spacecraft. Dr. Konopliv has authored or coauthored a dozen papers on planetary gravity fields and celestial mechanics.

Dr. Robert Lin (University of California, Berkeley, CA)

Dr. Robert Lin is a Co-Investigator for the Lunar Prospector mission, responsible for the spacecraft's Electron Reflectometer instrument. Dr. Lin was born in Kwangsi, China in 1942 and later became a U.S. citizen. He received a bachelor's degree in physics from Cal Tech in 1962 and earned a doctorate in physics from the University of California, Berkeley, in 1967. He is currently Professor of Physics and Associate Director of the Space Sciences Laboratory at U.C. Berkeley. Dr. Lin has developed experiments for numerous missions, including lunar orbiting Explorer 35 and the Apollo 15 and 16 subsatellites. Dr. Lin and his colleagues developed the electron reflectometer technique for remotely measuring surface magnetic fields on planetary bodies. He is the Principal Investigator for the plasma and energetic particle experiment on the Wind spacecraft, lead Co-Investigator for the Electron Reflectometer experiments on the Mars Observer and Mars Global Surveyor spacecraft, and Principal Investigator for hard X-ray and gamma ray spectrometer experiments for astrophysics and solar physics from balloons. He is also a Co-Investigator on Ulysses, ISTP Cluster and Equator spacecraft experiments. Dr. Lin has authored or coauthored 236 papers on solar, interplanetary, planetary, magnetospheric physics and astrophysics.

GLOSSARY

areology	scientific study of the history of Mars, as recorded in rocks
gamma ray	a type of high-energy radiation
highlands	heavily cratered light-colored regions of the lunar surface (the Moon's oldest rocks)
KREEP	an elemental composite material (used by scientists as a chemical tracer) consisting of K-potassium, Rare Earth Elements, and P-Phosphorous
Lunar eclipse	period in which the Earth is positioned so as to obscure the Moon from sunlight
Lunar Orbit Insertion (LOI)	spacecraft slows down in order to be captured by the Moon's gravity (placing it into lunar orbit)
maria	smooth, dark regions of the lunar surface (the Moon's youngest rocks)
mascon	concentrations of mass on the lunar surface
outgassing	venting of gases from the lunar interior
regolith	a mixture of fine dust and rocky debris (produced by meteor impacts) covering the lunar surface
selenology	scientific study of the history of the Moon, as recorded in rocks

Contacts

NASA Headquarters, Washington, DC

Douglas Isbell (202/358-1753, douglas.isbell@hq.nasa.gov), Public Affairs officer for the Office of Space Science, is the overall Lunar Prospector mission information manager

Ames Research Center, Moffett Field, CA

David Morse, Lunar Prospector Public Information Officer (650/604-4724, dmorse@mail.arc.nasa.gov), is in charge of news and press release drafts relating to the LP mission

Betsy Carter, Public Information Officer and Asst. for Lunar Prospector (650/604-2742, ecarter@mail.arc.nasa.gov), is assisting in all aspects of the LP media efforts

NASA Kennedy Space Center (KSC), FL

George Diller is the lead PAO for KSC-related Lunar Prospector activities. (407/867-2468, George.Diller-1@pp.ksc.nasa.gov)

Lockheed Martin

Buddy Nelson is the Lunar Prospector Public Information Officer, (650/ 424-3110, 510/797-0349, buddy1@home.com)

Evan McCollum is responsible for media relations on the Athena launch vehicle (303/977-5937, evan.d.mccollum@lmco.com)

Rebecca Gray is responsible for media relations on the Athena launch vehicle (303/977-6893, rebecca.b.gray@lmco.com)

Los Alamos National Laboratory, Los Alamos, NM

John Gustafson, Public Information Group (505/665-9197)

Spaceport Florida Authority

Edward Ellegood, Director of Policy and Program Development (407/868-6983, sfa@digital.net)

University of Arizona, Tucson, AZ

Lori Stiles, News Services, Science Writer (520/626-4402, lstiles@u.arizona.edu)

University of California at Berkeley, Berkeley, CA

Robert Sanders, public Information Representative and Science Writer, (510/643-6998, rls@pa2.urel.berkeley.edu)

NASA Goddard Space Flight Center (GSFC), Greenbelt, MD
William Steigerwald, Public Affairs Specialist, Space Sciences (301/286-5017, William.A.Steigerwald.l@gsfc.nasa.gov)

NASA Jet Propulsion Laboratory (JPL), Pasadena, CA
Mary Beth Murrill, Senior Public Affairs Officer (818/354-6478, mary.b.murrill@jpl.nasa.gov)